ATTACHMENT 4

STUDY FOR PARTICULATE CONTROL EQUIPMENT
ELECTROSTATIC PRECIPITATORS AND FABRIC FILTERS
INTERMOUNTAIN POWER PROJECT

Task No. PAA66

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EXECUTIVE SUMMARY

The objective of this study is to compare electrostatic precipitators and fabric filters applied to the Intermountain Power Project (IPP) as the particulate collection device.

After thoroughly examining the advantages and disadvantages of these two particulate control equipment alternatives, the selection of fabric filter is recommended. Major reasons for this recommendation are summarized as follows:

1. The performance of electrostatic precipitators depends very much on coal and fly ash properties, but this is not usually true for fabric filters. IPP has not obtained confirmed sources of coal supply and, furthermore, it is almost impossible to secure consistently uniform coal properties during the life of the plant. The uncertainty of coal properties makes the fabric filter a better choice than the precipitator.

2. In general, fabric filters have higher collecting efficiencies than electrostatic precipitators and, moreover, they can consistently maintain this high efficiency. A well designed precipitator can achieve very high efficiency, but this efficiency tends to vary, depending on coal properties and operating conditions. Field experiences have shown that precipitators often gradually deteriorate after a few weeks of operation and have to be shut down for washing and other maintenance to maintain high efficiency.

3. Fabric filters are more effective in reducing plume opacity than electrostatic precipitators. The major contributions for visible plumes are fine particles in the size range of 0.2 to 1.0 micron. Fabric filters can collect these fine particles more effectively than precipitators can. Plume opacity is an important consideration for selecting particulates control device because IPP is located in an area where aesthetics is a very sensitive issue.

4. Cost comparisons show that the fabric filter is less expensive than the precipitator. The fabric filter also has the potential to further reduce its costs by increasing bag life.

5. In the western states where low-sulfur coals are the major source of fuel, more utilities have committed themselves to fabric filters than those committed to precipitators. It appears that the performance record of fabric filters has already convinced electric utilities of their superiority over precipitators.

In this study, the favorable results for fabric filters make the recommendation obvious. But it should be noted that the conclusions are only applicable to generating stations burning low-sulfur coals and under certain conditions. It is not the intention of this study to generalize the results for all cases.

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I. Introduction

The purpose of this report is to provide technical and economic evaluations of the alternative methods of particulate emission control for the Intermountain Power Project (IPP) Generating Station located in the Delta-Lynndyl area of Central Utah.

A key environmental problem facing the electric utility industry is the increased emphasis by regulatory agencies on the application of high efficiency particulate control devices to pulverized coal-fired boilers. The particulate emission limit initially set by the Environmental Protection Agency (EPA) was 0.1 lb/10^6 Btu. Under the Clean Air Act of 1977, EPA promulgated on June 11, 1979, a New Source Performance Standard for particulates of 0.03 lb/10^6 Btu, which is more than three times stricter than the previous limit. In the Conditional Permit to Commence Construction and Operation of IPP by EPA Region VIII, the particulate emissions are further limited to only 0.02 lb/10^6 Btu. This stringent particulate emission limit has a definite impact on the selection of particulate control equipment.

Electrostatic precipitators have been the dominant particulate collection device in the electric utility industry for many years. However, increasingly stringent emission standards have led to substantially higher costs for precipitators. These costs have increased so high that fabric filters (baghouses) have become a competitive alternative in achieving cost effective control of particulate emissions.

Besides cost considerations, the stringent emission limits also have placed fabric filters in a technically favorable position, based on data from increasing numbers of recent fabric filter applications to utility boilers.

This report compares the advantages and disadvantages of fabric filters and precipitators in light of such factors as coal properties, visibility, availability, other utilities' experiences, costs and related regulations. A final recommendation is made based on these comparisons.

II. Technical Discussion

A. Electrostatic Precipitator

Precipitators have operated successfully over a number of years for a wide range of particle sizes for the electric utilities. The basic precipitation process takes place in three steps: first, the particles in the flue gas are charged by bombardment of gaseous ions that are produced by means of a high voltage corona discharge. The charged particles then migrate to a collecting electrode of opposite polarity; and finally, the collected material is disloged by mechanical forces to an appropriate storage space for subsequent disposal.

1. The Performance of Precipitators

The performance of a precipitator is sensitive to a number of items, which are sometimes interrelated with each other. A brief discussion of them is given here:

a. Coal Characteristics

The performance of an electrostatic precipitator is affected throughout its operating life by the coal burned in the boiler. A major coal characteristic of concern is its fly ash resistivity. The resistivity is a function of 1) flue gas temperature, 2) fly ash mineral analysis, 3) flue gas moisture, and 4) sulfur content in the coal. Western low-sulfur coals are noted for their high resistivity ash and difficulty to precipitate. Figure 1 presents typical curves of electrical resistivity as a function of flue gas temperature and sulfur content in the coal.(1) To overcome the difficulties of high resistivity fly ash, three methods are generally employed:

1) to oversize the precipitator, 2) to inject gas conditioning chemicals, 3) to use the precipitator before the air preheater (hot-side precipitator). But any one of these has its own problems to be solved.

Sodium content in the coal also affects the performance of precipitators; the coal with low sodium content produces unsatisfactory precipitator performance. Field operating data shows that a reduction in sodium content from three percent to one percent produces almost a 50 percent decrease in effective migration velocity. A 50 percent decrease in migration velocity requires approximately a 50 percent increase in required precipitator size. This approximation can be found from the Deutsch equation which is the basis for precipitator design.

Precipitator specifications should be based on coal properties. The more coal information one can obtain prior to issuing the precipitator specification, the less chance there will be of a performance problem. Thought should also be given to coal properties which may be encountered many years into the future. Coal core sample analysis should be required from areas of mines which will be mined many years into the future.

b. Specific Collection Area

Specific Collection Area (SCA) is defined as the area of collection surface per 1000 actual cubic feet per minute of flue gas flow. The commonly used unit is $ft^2/1000$ acfm, which generally describes the size of a precipitator. SCA is dependent on required collection efficiency, particle size distribution, ash chemical properties, altitude, and others.

The use of electrostatic precipitators to collect 90 percent or more of the fly ash at coal burning power plants has been commonplace for 50 years. At the collecting efficiency of 90 percent, precipitators can perform very well using SCA well under 200. In recent years, however, more and more stringent particulate emission standards push the collecting efficiency to 99 or 99.5 percent for new coal-fired power plants in the United States. This requires a precipitator with much larger SCA. For example, a precipitator for 99 percent efficiency is at least twice as big (and costly) as one for 90 percent efficiency, for any given type of fly ash from a given flue gas composition at a given temperature and humidity.

To achieve adequate performance, the trend for precipitator design is that a much larger SCA is used for new power plants than for the existing ones. For example, under the New Source Performance Standard of 0.03 lb per million Btu, EPA has predicted 1000 SCA for low-sulfur western coal.[2] The larger size precipitator of course affects the capital as well as operating costs.

c. Flue Gas Flow Distribution

Poor gas flow distribution can seriously impair the performance of a precipitator. This poor distribution results from poor inlet duct arrangement or from fluctuations in boiler load. With gas flow at a high velocity through some parts of the system and at a low velocity through other parts, the overall collection efficiency is reduced. This reduction is caused by the effect of creating different specific collection areas across the face of the precipitator. High velocity areas have the effect of reducing the precipitator collection surface per unit of gas flow.

d. Boiler Operating Conditions

Boiler operating conditions can have a dramatic effect on a precipitator's performance. Flue gas flow may vary due to variations in the coal properties. There may be periods when operation with increased boiler excess air is required. The leakage of air preheaters will increase with time. All these operating conditions will affect the performance of a precipitator.

Sometimes oxygen imbalances occur across the boiler. The imbalance forces the operator to boost the total air flow in order to operate with a safe oxygen level in all areas of the boiler. This increase of air flow can usually affect the precipitator's performance. Also variation in temperature across the flue gas can result in significant differences in temperature across the precipitator which in turn influences precipitator performance.

2. Cold and Hot precipitators

Precipitators are classified as cold side units when they have been installed downstream of the air preheater where gas temperatures are in the range of 250 deg F to 350 deg F. Hot precipitators are those installed upstream of the air preheater where gas temperatures are in 650 deg F to 750 deg F range.

Cold precipitators have been used for many years in the utility industry burning high-sulfur coals. As the result of more stringent rules on SO_2 emissions, utilities started to consume more low-sulfur coals for power generation. High ash resistivity is always associated with low-sulfur coal which results in lower collection efficiency. Since ash resistivity can be reduced by increasing gas temperature, the hot precipitator was introduced for units burning low-sulfur coal.

A hot precipitator treats a larger flue gas volume because of the elevated temperature. Besides, other problems, such as air leakage and differential thermal expansion between different parts, cause operating difficulties.

In the past few years, the discussion to install hot or cold precipitator has always been controversial. Vendors have taken opposing sides of the argument. For low-sulfur coal, the size of a cold precipitator can be enlarged to achieve the same collection efficiency as a hot precipitator. It seems that with proper attention to design consideration and good operating and maintenance practices, both can be competitive alternatives.

3. American and European Designed Precipitators

American designed precipitators use a weighted wire for the discharge electrode and a light gauge flat plate for the collecting electrode. They utilize rapping forces of 10 to 50 g's (10 to 50 times of the acceleration of gravity) to drive the dust into the hoppers. The light weight construction does not allow very high intensity rapping, which is required for the high resistivity ashes. The basic advantage of this design is the relatively low capital cost.

The main features of a European designed precipitator are: 1) the discharge electrode is supported with a rigid frame to reduce wire breakage, 2) the rapping intensity is at least 100 g's, (100 times the acceleration of gravity). The European design is usually stronger and larger than the American design. The European design costs more but is more capable of handling high resistivity fly ash and maintaining performance efficiency.

B. Fabric Filter

The basic design of a fabric filter unit is simple and straightforward. It employs the filtering capability of high-efficiency woven or felted fabric to form tubes or bags that are placed in a housing structure called a baghouse. (In this report, the baghouse and the fabric filter are meant to be the same equipment and are used interchangeably.) The high efficiency requirements of particulate removal and longer bag life have made the application of the baghouse economically competitive with electrostatic precipitators.

When flue gases pass through the cloth filter, particulates are trapped in the fabric mesh. The collection process is enhanced by the particulate cake that is built up on the fabric surface. This particulate cake acts as a filter to the finer particles in the flue gas stream. As this "filter cake" increases in thickness, the pressure drop across the filter surface increases. In order to avoid an excessively high pressure drop across the bag surface, the filter bags are periodically cleaned to remove most of the built-up filter cake. The filter cake then falls into an ash collection hopper beneath the filter bags for eventual removal.

1. The Performance of Fabric Filters

Fabric filter units are not sensitive to fly ash resistivity and have proven themselves capable of high particulate removal efficiencies to produce very low outlet dust loadings. To use western low-sulfur coal under existing stringent emissions regulations, these two factors put baghouses on a favorable or at least competitive position to precipitators.

Major limitations to the successful performance of baghouses are flue gas temperature and pressure drop. Temperature is limited to about 550 deg F at the high end to prevent bag damages. At the lower end of the temperature scale, temperatures are limited to about 30 deg F above the water dew point to prevent bag plugging by condensed moisture. During boiler start-up, the flue gas is bypassed from the baghouse to avoid bag damages. In addition to the bypass, the baghouse sometimes is heated to reach the temperature above the dew point before being put back on line. Pressure drop across bags depends on the gas volume filtered through a unit area of cloth which is called the air-to-cloth ratio. Too high an air-to-cloth ratio leads to increased filter resistance, and hence, high pressure drop. This high pressure drop causes excessive bag wear and reduces bag life. It may also cause load reductions due to fan power limitations.

Baghouse configuration also has a significant effect on baghouse performance. Multi-cell construction is necessary for good performance. The general approach is that two cells can be taken off-line at full load, one undergoing cleaning process and one undergoing maintenance. With this design, even the largest steam generator can be operated with limited downtime for repair or maintenance, thus enhancing the availability of the particulate control system. When the boiler is operated at low loads, it is often necessary to shut off part of the baghouse cells to keep gas temperature high enough to prevent moisture condensation.

2. Fabric Filter Sizing

Basically, a fabric filter is a device producing a relatively constant outlet grain loading even with various ash contents in the coal. Thus, the required particulate removal efficiency has little impact on the size of the baghouse.

The most significant factor in determining baghouse size is the air-to-cloth ratio (A/C ratio). Also the size of the individual bags (diameter and length of the bag) will affect the baghouse size. In order to limit the pressure drop to under five inches water, the A/C ratio of two is considered to be a conservative criteria for sizing a baghouse for a coal-fired power plant.(3)

3. Cleaning Mechanism

All baghouses operate in basically the same way, and the main variations between different baghouses are in the type of fabric used and the fabric cleaning mechanism. In fact, it is the cleaning method that characterizes one type of baghouse from another.

Filter bags are cleaned by three basic methods. These include shaking, reverse gas flow, and pulse jet. Sometimes more than one of the cleaning methods are used in combination or the baghouse is designed so that the operator can select operation in either a single cleaning mode or in a combination of cleaning modes. It is generally believed that reverse gas flow is the best method of cleaning because it does not subject the fabric to severe stress as the case with shaking or pulse jet.

a. Shaking

The shaking method cleans the bags in a manner similar to shaking a rug. Before the shaking starts, dirty gas flow is shut off in a single compartment. The bags in this compartment are then shaken at the top to dislodge the dust which is then collected in the hopper below. The shaking mechanism design must be especially adapted to the type of fabric used. Shaking is a vigorous cleaning method and can be accomplished in various degrees of severity. Too violent shaking can damage the bags. Too gentle shaking may fail to dislodge deeply embedded fly ash. Consequently, controls are needed to permit adjustment of the intensity, frequency and duration of shaking.

b. Reverse Gas Flow

With reverse gas cleaning, the clean gas outlet of a cell is shut off first. Following a brief no flow period for dust settling, clean flue gas is introduced in a reverse flow to gently collapse a part of the bags and dislodge the ash, allowing it to fall into the hoppers. Following another quiescent no-flow period, the cell is returned to service. Typical cleaning processes are usually so designed that compartments (or cells) are continuously cleaned on a cyclic basis, one at a time. The period between cleaning cycles can be adjusted to accommodate various inlet grain loadings produced by different coal ash contents. Proper control of the frequency of cleaning and duration of cleaning will maintain an acceptable pressure drop across the entire baghouse. Normally, baghouses with this cleaning method and the shaking method are compartmentalized so that one compartment can be isolated for cleaning, while the remaining compartments handle the total gas flow.

c. Pulse Jet

With pulse jet cleaning, each individual bag is subjected to a high intensity blast of air from inside of the bag. The pulse action expands the bag and forces the dust cake from the exterior side of the bag. A venturi of diffuser nozzle is usually mounted on the top of the bag and assists the pulse jet by aspirating secondary air. Pulse jet units are usually designed so that pulse time, the interval between pulses, the number of pulses, and the frequency of cleaning can be adjusted.

The cleaning can be accomplished either while the bag is filtering combustion gases or with the compartment off-line.

4. Pressure Drop

Pressure drop through the fabric filter system is one of the major concerns to the potential user. Most baghouse systems are designed for a flange-to-flange pressure loss of four to eight inches water. Many factors affect pressure drop in the baghouse, such as A/C ratio, inlet grain loading, frequency of cleaning, duration of cleaning, and the number of compartments. The dominating factor is the A/C ratio. By averaging data from different sources, R. M. Jensen[4] of Bechtel Power Corporation derived an equation relating pressure drop and A/C ratio as below:

$$\Delta P = 0.566V^{1.8}$$

Where ΔP is the pressure drop in inches of water column and V is A/C ratio in feet per minute. Figure 2 presents the relation between pressure drop and A/C ratio. It should be noted that the curve in Figure 2 is only an average value and cannot be used for design purposes; but the relationship is very clearly demonstrated.

With properly designed A/C ratio, the pressure drop can be limited by the frequency and duration of cleaning. Two different controls can be employed to limit pressure drop, timing controls or pressure controls. With timing controls, the compartments of a baghouse are cleaned at predetermined intervals which keep the pressure drop below certain values. With pressure control, a predetermined cleaning cycle is initiated each time the pressure drop across the baghouse exceeds certain values.

5. Baglife and Bag Material

The fabric filter baglife is a function of many variables such as operating A/C ratio, pressure drop, cleaning method and its intensity and frequency, chemical properties of fly ash, particulate loading and particulate size distribution. Vendors usually guarantee two-year bag life, but based on actual field experience, bag life of three or more years can be expected.

Selection of bag material is one of the most important factors in prolonging bag life. The choice of fabric is dependent upon the inlet gas temperature, particulate chemical characteristics, particle size and concentration, acid dew point temperature, and moisture content of the gas stream. To withstand the operating temperatures and sulfur oxide content from coal-fired boilers, the only commercially proven fabrics are woven fiberglass and felted teflon according to E. W. Stenby of Stearns-Roger Inc.(5)

6. Design Considerations

Important considerations in designing baghouses for coal-fired utility boilers are listed as below:

a. Use conservative air-to-cloth ratio. The gross A/C ratio should be about 2 to 1. With one or two compartments out for cleaning and maintenance, the ratio can be higher, but never exceeding 2.5 to 1. With proper cleaning methods, the 2 to 1 ratio is consistent with acceptable pressure drop, long bag life and good particulate collection efficiency.

b. Design pressure drop should be a nominal four inches water with maximum of six inches water. Based on field testing data, the Environmental Protection Agency (EPA) reported that using an air-to-cloth ratio of 2 to 1, a pressure drop of five inches water or less can be achieved.

c. Use reverse air cleaning method.[3] This is the most gentle method for filter bag cleaning. The cleaning cycle should be automatically controlled by monitoring baghouse pressure drop. Once the pressure drop reaches a present limit, the cleaning cycle should be started. A timed cleaning cycle should also be provided.

d. The baghouse should be designed to operate at full load with two compartments off-line, one for cleaning and one for maintenance. This arrangement will increase the baghouse reliability and availability.

e. Provide low gas inlet velocity to each compartment with sufficient ash hopper storage capacity to minimize turbulence and reentrainment of fly ash.

f. Monitor and control flue gas temperature at baghouse inlet to stay at least 30 deg F above the water dew point. An air heater bypass should be provided for increasing flue gas temperature when the boiler is operated at low loads.

g. Woven fiberglass with teflon coating should be considered as bag material. Field testing indicated that this type of bag material can achieve very high particulate removal efficiency.(6)

h. Easy and safe bag replacement arrangement should be provided.

i. Opacity and pressure drop monitoring instruments should be installed to detect failures as early as possbile.

j. Provide proper bag tensioning to achieve good performance and extended bag life.

k. The heating of baghouses and hoppers may be necessary under extremly cold weather.

III. Cost Estimates

Costs of electrostatic precipitators and fabric filters are compared and discussed in this section from three different sources. The first one was reported by EPA for their background information.(3) The second source was developed by Stearns-Roger Engineering Corporation and Electric Power Research Institute.(7) The third one came from a study for IPP by GCA Corporation.(8) It should be noted that the purpose of these cost estimates is to give adequate comparisons between electrostatic precipitators and fabric filters on the same basis. These costs do not necessarily reflect actual capital and annualized costs because of different methods of calculations by different sources.

A. EPA Cost Estimates

To cover a realistic spread of conditions that might occur within the electric utility industry, EPA's estimates considered two types of coal, three different control systems and four plant sizes. The two types of coal were: one containing 0.8 percent sulfur, 8.0 percent ash, and a heat value of 10,000 Btu/lb; the other one containing 3.5 percent sulfur, 14 percent ash, and a heat value of 12,000 Btu/lb. Three control systems were fabric filter, electrostatic precipitator and venturi scrubber. The plant sizes were 25, 100, 500, and 1000 MW. For the application to IPP, only low-sulfur coal with fabric filter and electrostatic precipitator are considered here.

1. Capital Costs

Capital costs are in 1980 dollars which include indirect costs covering interest during construction, field overhead, engineering, freight, offsites, taxes, spares and start-up. These indirect costs are estimated as 33.75 percent of installed cost. Also, a contingency allowance of 20 percent of the total is added to reach the final turnkey investment.

For fabric filter, an air-to-cloth ratio of 2:1 is used for the estimates. For the electrostatic precipitator, three sizes of precipitators are used because the removal efficiency is a function of the plate area, and the cost is also a function of the plate area. The sizes vary from 400 to 650 square feet per 1000 acfm.

2. Annualized Costs

The total annualized costs include direct operating costs and annualized capital charge. Direct operating costs include fixed and variable annual costs such as: labor and materials needed to operate equipments, maintenance labor and materials, utilities including electric power, fuel, water and steam, and disposal of liquid and solid wastes. Annualized capital charges include capital recovery factors representing 10 percent interest over a 20-year life. An additional four percent of total investment was also added to cover general administration, property taxes, and insurance. The mills per kilowatt-hour were computed using a 65 percent operating factor.

Table 1 presents capital and annualized costs for both fabric filters and electrostatic precipitators. For a power plant of 820 MW such as for the IPP unit, the capital cost for a fabric filter is about $45 million, and the capital cost for an electrostatic precipitator is $62 million. The annualized costs are 1.86 mills/kWh for the fabric filter and 3.55 mills/kWh for the precipitator. These numbers were interpolated between 500 MW and 1000 MW. The economic advantage of fabric filter over precipitator is clearly shown here. A specific collection area (SCA) of 650 was chosen for the precipitator cost estimation, because for a stringent regulation of 0.02 lb/10^6 Btu emission rate, this is a more realistic number to be used.

B. Stearns-Roger Cost Estimates

The economic findings by Stearns-Roger was sponsored by the Electric Power Research Institute and presented in 1979. The cost estimates were based on a 500 MW pulverized coal-fired boiler burning four different types of coal. The coals were Wyoming subbituminous (0.56 percent sulfur), North Dakota lignite (0.68 percent sulfur), Alabama bituminous (1.9 percent sulfur) and Eastern bituminous. Since a Utah coal was not included in the study, the costs using Wyoming subbituminous coal are presented here, because the Wyoming coal is the most similar to the Utah coals that are expected to be used at IPP.

Five different particulate collection systems were considered: hot side precipitator, cold side precipitator, fabric filter with 20 compartments and two-year bag life, fabric filter with 20 compartments and four-year bag life, and fabric filter with 40 compartments and two-year bag life.

1. Capital Costs

Capital costs were estimated for a range of outlet emission levels. Included in the estimates are materials and labor for installation of the collectors, hoppers, support steel, ducts nozzles, dampers, fans, expansion joints, ash-handling equipment, insulation, and other miscellaneous items. Indirect costs and ten percent contingency allowance are also included in the cost estimation.

Figure 3 shows capital cost in 1980 dollars for several different particulate control systems. The costs were escalated from 1978 to 1980 using a 9.4 percent annual inflation rate. It is demonstrated in the figure that the capital cost for precipitators increases as the outlet emission is reduced. Since fabric filters operate at high particulate removal efficiencies with relatively constant outlet loading, the capital cost is essentially constant for the range of emission limits.

2. Annualized Costs

The annualized costs combine capital investment, operating and maintenance costs, and power requirements. For Stearns-Roger analysis, the following factors were used:

Minimum acceptable return	11%
Fixed charge rate (depreciation, insurance, etc.)	16%
Interest during construction	8.5%
Escalation (fuel, material and labor)	7%
Plant capacity factor	70%

Figure 4 gives annualized costs in mills/kWh as the function of particulate emission limits. The costs were also escalated from 1978 to 1980 using a 9.4 percent annual inflation rate.

Both capital cost and annualized cost are higher for electrostatic precipitator than for fabric filter as demonstrated in Figures 3 and 4. The differential cost is wider when lower particulate emission limit is approaching. The cost estimates are somewhat lower than those presented by EPA, because in the EPA model a more conservative method was used in its calculation. Nevertheless, the trend for the costs of fabric filters and precipitators are clearly demonstrated in both models.

C. GCA Cost Estimates

GCA Corporation, under a contract with the Department, made their cost estimates based on three different sources. The first source was derived from theoretical and existing plant data. The second source was based on cost models developed by the Department of Energy (DOE) and Research-Cottrell, Inc. (RC). The last one was cost information obtained by GCA from ten equipment manufacturers.

Both DOE and RC cost models were used to calculate capital costs and annualized costs for fabric filter and precipitator control systems for IPP. The costs from these two models can be used for comparison purposes but not for the representation of the actual equipment and operating costs. By comparing the results of the two models with vendor estimates, GCA suggested that a baghouse appeared to be the economical choice, when the precipitator's specific collection area exceeds 600. This comparison was based on fabric filter A/C ratio of two.

GCA suggested that vendor's cost information should be viewed as the most reliable and accurate since the various vendors responded directly to fuel and system specifications. Among the response received from the vendors, four quoted prices for a cold precipitator only, two quoted prices for a baghouse only, and four quoted prices for both control systems. All equipment were designed to achieve an outlet loading of 0.03 lb/10^6 Btu. Summaries of all cost estimates are presented in Table 2 with the ten vendors identified by letter code A through J.

1. Capital Costs

As presented in Table 2, the capital costs vary over a wide range. Installed costs for fabric filter ranged from \$12.6 millions to \$18.4 millions; those for precipitators are from \$13.5 millions to \$24 millions. Based on the capital cost, it appears that the fabric filter would be the economical choice compared to the electrostatic precipitator.

The costs suggested by vendors are much lower than those estimated by EPA or S-R. The major reason for the differences is that the installed costs did not include indirect costs and contingency allowances.

2. Annualized Costs

GCA calculated annualized costs based on data provided by Vendor H. for the following reasons:

- Vendor H's information is the most detailed.
- They appear to be unbiased because they have proposed both a baghouse and a precipitator.
- The vendor is a leader in the field of control equipment design and manufacture.
- The specific collection area is in the middle of the range quoted for all ESP equipment.
- The baghouse quoted is conservative in design with respect to A/C ratio and cleaning method.

The annualized costs are given in Tables 3 and 4 for the electrostatic precipitator and fabric filter, respectively. Both costs are a little over one mill/kWh. The cost can be shifted in favcr of fabric filter if bag life of more than two years is achieved.

IV. Comparisons between Electrostatic Precipitator and Fabric Filter

In order to have any meaningful comparison between electrostatic precipitator and fabric filter, two important factors must be considered.

1. The extremely stringent New Source Performance Standards for particulate emissions of 0.03 lb/10^6 Btu was promulgated by EPA on June 11, 1979. To make things worse, IPP has been committed to even less particulate emissions of 0.02 lb/10^6 Btu as indicated in the Conditional Permit to Commence Construction and Operation of IPP Generating Station.

2. Only low-sulfur western coal will be burned in the IPP boilers, and sources of coal supply have not been confirmed. A coal validation study is now in progress to identify coal sources for IPP. Prior to the completion of this report, the results of this study were not available.

In comparing these two particulate collection devices, considerations are given to coal properties, performance efficiencies, opacity, actual field experience, reliability, costs and others. Based on results of the comparisons, a recommendation for the selection of equipment was made.

A. Coal Properties

In order to properly evaluate particulate collection devices, one must know the coal properties for properly sizing the equipment. Of the coal analysis parameters, sulfur content, ash content and heating value are of greatest significance.

Recently, it has been found that sodium content is also an important factor to affect the collectibility of particulates for low-sulfur coal applications.

Currently, IPP has not obtained confirmed sources of coal supply. The best available data was a range of values for coal properties as presented in Table 5. A range of values does not provide an accurate assessment of the fuel characteristics.

Under today's high efficiency requirements, the electrostatic precipitator manufacturers need more and more accurate information of coal properties for proper precipitator sizing. To some precipitor manufacturers, specification of "average" or "broad range" coal and ash properties is becoming an unsatisfactory situation. Instead, a full presentation of all drilling core analyses or a statistical distribution analysis of the range is preferred. Without an adequate representation of coal samples, the design of an electrostatic precipitator to assure an extremely high removal efficiency is almost impossible.

Fabric filters have the advantage of insensitivity to coal and fly ash chemical characteristics. Electrical resistivity is not a consideration in fabric filter design. It is generally agreed that coal properties have only limited effect on fabric filter operations.

Since only a broad range of coal and ash properties can be provided, and future coal sources are uncertain during the life of the plant, fabric filter is the preferred choice of the two.

B. Particulates Collection Efficiency

Particulate collection efficiency of 99.5 percent and over is required under the very stringent emission limitation of 0.02 lb/10^6 Btu. Preliminary calculation, based on highest ash content in coals, shows that efficiency of at least 99.71 percent is required for the IPP units.

Although electrostatic precipitators are designed as constant efficiency devices, the efficiency usually varies with coal and ash properties, flue gas distribution, and temperature fluctuations. It has been experienced by the utilities that precipitators gradually deteriorated after a few weeks of operation, and the units have to be shut down for washing and other maintenance to maintain high efficiencies.

Of all the factors affecting the precipitator performance, fly ash resistivity is the most serious one. As shown in Figure 1, low-sulfur coals have much higher fly ash resistivity than high-sulfur coals. The high resistivity fly ash can lead to back corona and spark erosion within the precipitator, which may shorten component life and reduce collecting efficiency. Since fly ash resistivity is likely to change during the plant lifetime, which is expected from a new coal source, precipitator performance becomes uncertain. Under the strict particulate emission regulations, a small drop in efficiency would cause a violation of the law which could cause the plant to be shut down.

A survey was conducted by GCA[8] and also by the Department to investigate the performance of electrostatic precipitators. The results are presented in Table 6. With only a few exceptions, the survey shows that the performance test efficiencies generally do not meet the design effficiencies. These are only small samples, so it does not suggest any significant trend for precipitator failures. But, it does show the difficulty for precipitators to achieve design efficiency due to various problems.

Contrarily, properly designed fabric filters can meet very strict emission requirements, and its efficiency seldom varies. The ability to keep low emission rates is mainly due to its independence of coal and ash characteristics, fuel gas distribution and temperature fluctuations.

It can be generally concluded that fabric filters will be able to consistently maintain compliance of a very stringent rule on any low-sulfur coal the plant can burn, but electrostatic precipitators may not be able to maintain continuously high efficiencies because of the uncertainty of coal properties and various operating conditions. Thus, from the efficiency point of view, the fabric filter is a better choice.

C. Opacity and Fine Particles

Currently, the standard for opacity is limited to 20 percent over six minutes average time. This is a standard that is not difficult to comply with by fabric filters or a well-designed precipitator. Therefore, a clear stack should be achieved as much as possible.

Fine particles in the range between 0.2 to 1.0 micron are the major contributors for visible plume since fly ash of this size range is a very efficient light scatterer. Blue light is in the range of 0.4 to 0.5 micron wavelength. More particles of this size range will interfere with blue light, producing visible plume.

Besides the visibility problems, fine particles may also cause adverse health effects. Increasing concern over these potential health effects would presumably force emission limitation standards based on particulate size as well as total mass. For example, the State of New Mexico has already instituted a standard which limits emissions from utility steam generators to 0.05 lb per million Btu total particulates and also more stringent 0.02 lb per million Btu for particulates less than two micron diameter. Similar fine particulate standards are also under consideration by the Environmental Protection Agency.

Generally, higher opacity can be expected from precipitator emissions than from fabric filters because fabric filters are more effective in removing fine particulates in the size range of 0.2 to 1.0 micron, which are the material primarily responsible for opacity problems. Available data shows that collecting efficiency for an electrostatic precipitator is approximately proportional to particle diameter over a size range of 0.2 to 20 micron. A recent study on electrostatic precipitator performance for a large utility boiler burning low-sulfur coal found that collection efficiencies of 99.6, 98 and 90 percent were observed for particles having diameters of 20, 2 and 0.2 micron, respectively.[9] Similar findings were also reported elsewhere.[10] Figure 5 presents measured fractional efficiencies versus particle diameter for a cold-side precipitator burning low-sulfur coal. It clearly demonstrates the lower collection efficiency in the range of 0.2 to 1.0 micron which is the major cause of visible plumes.

To compare the collecting efficiencies for fine particulates between fabric filters and electrostatic precipitators, Table 7 gives, as an example, a proposed efficiency guarantee by a vendor.[11] The collection efficiency for fabric filter is constant at 99.8 percent and independent of particle sizes, but precipitator efficiencies vary from 95.19 percent for 0.3 micron particles to 99.93 percent for 10 micron particles. This difference of efficiencies can make a large difference in opacity from stack emissions.

D. Costs

In Section III, three sources of cost comparison have been presented. The comparisons covered those based on plant sizes, emission limitations and budgetary costs provided by manufacturers. Although those costs do not necessarily represent actual capital and annualized costs because of different methods of calculations, they do give adequate comparisons between electrostatic precipitators and fabric filters on the same basis. All three sources present the same conclusions: The fabric filter is a more economic choice than the precipitator under the current strict emissions limitation. In its background information, EPA has stated that fabric filters are the more economic choice for low-sulfur coals and electrostatic precipitators for high-sulfur coals.

E. Field Experiences

A telephone survey was taken to investigate the utilities' field experience on the performance of electrostatic precipitators and/or fabric filters. With few exceptions, only those utilities which are located in the western region of the United States and burn low-sulfur coals, are included in the survey. A list of utilities that have been contacted are given as follows:

Arizona Public Service
Colorado - Ute Electric Association, Inc.
Commonwealth Edison Co.
Department of Public Utilities, City of Colorado Springs
Houston Power and Light
Nebraska Public Power District
Nevada Power Co.
Otter Tail Power Co.
Public Service of Colorado
Public Service of New Mexico
Salt River Project
San Antonio Public Service Board
Sierra Pacific Power Co.
Southern California Edison Co.
Southwestern Public Servie Co.
Texas Utilities Services, Inc.
Utah Power and Light

Also, contacts were made to several architecture and engineering firms and a research institute for design information. They are:

Bechtel Power Co.

Black and Veatch

Brown and Root

Industrial Clean Air, Inc.

Stearns-Roger, Inc.

Stone and Webster

Electric Power Research Institute

Many utilities have field experiences with both electrostatic precipitators and fabric filters, and their general opinions can be summarized by the following:

1. All of the utilities surveyed had a visible plume problem with electrostatic precipitators even though some of them could marginally comply with particulate emission regulations; those with fabric filters claimed clear stacks almost all the time.

2. Hardly any electrostatic precipitators surveyed met the particulate emissions regulations all the time. They might comply right after being washed and "tuned up", but gradually deteriorated to violate the regulations.

3. The reason given by those who selected fabric filter was always that they had unsatisfactory experiences with precipitators; those who operated fabric filters never expressed their dissatisfaction with them. As a matter of fact, all utilities which had installed fabric filters, selected the same equipment for their future plants.

4. The only problem with fabric filters is the high pressure drop, as experienced with Southwestern's Harrington Unit 2. But, the problem is solvable with the use of proper cleaning methods and the specification of a lower air-to-cloth ratio.

5. All people contacted favored fabric filters over precipitators, especially when firing Western coals and under today's strict regulations.

The survey clearly shows two things: first, the utilities have already established confidence on fabric filter's performance; second, with regard to opacity and high collection efficiency, fabric filters are definitely better than electrostatic precipitators.

F. Future Trend for Western Coal Applications

Electrostatic precipitator have been used by electrical utilities as the particulates control equipment for many years, but recently, fabric filters are rapidly catching up especially in the western states where low-sulfur coals are the primary source of fuel. In fact, utilities in the western states have committed more fabric filters than electrostatic precipitators for their future generating units.

An investigation of western utilities' future installation of particulate collection devices shows that units with a total of 7,250 MW capacity have already selected fabric filters, with 2,400 MW leaning in this direction. Table 8 gives a list of units committed to fabric filters in the future. Table 9 presents a list of western utilities which selected precipitators for their future plants, totalling 3,840 MW capacity.

By comparing data from Table 8 and Table 9, several interesting facts are revealed:

1. The generating capacity committed to fabric filters is more than double those committed to precipitators.

2. No precipitator was purchased for installation beyond year 1981.

3. Most stations which previously selected precipitators have switched to fabric filters for their newer units. For example, Craig Nos. 1 and 2 were installed with precipitators, but Craig No. 3 will have fabric filters; Parish No. 7 has a precipitator, but Parish No. 8 will have a fabric filter; Gentleman Nos. 1 and 2 have precipitators, but Gentlemen No. 3 will have a fabric filter; Hunter Nos. 1 and 2 have precipitators, but Hunter Nos. 3 and 4 will have fabric filters, Coronado Nos. 1 and 2, which the Department is a partial owner, have precipitators, but Coronado No. 3 will have a fabric filter.(12)

The future trend for western utilities clearly indicates that the fabric filter is a more favorable choice than the precipitator.

G. Other Considerations

1. Combined with SO_2 Dry Scrubbers

IPP now is considering the use of a dry scrubber for SO_2 removal. If the dry scrubber is selected, the fabric filter is a natural choice for the particulate removal device since most manufacturers use the dry scrubber and the fabric filter as a package. Some manufacturers have suggested the combination of dry scrubber with a precipitator. The feasibility of this combination is uncertain because the dry scrubber makes the coal ash properties even more complicated before entering the precipitator.

2. Availability and Reliability

No utility keeps complete availability data for precipitators or fabric filters, because it is so difficult to estimate availability of one single piece of equipment when so many others are involved in the power plant operation. But it can generally be expected that the availability of a fabric filter is better than a precipitator, because on-line maintenance is possible for fabric filter operation but is not practical for a precipitator.

3. Simplicity

Fabric filters are based on a very simple method of filtering without complicated control equipment. A simple equipment is less problem prone and easy to operate. Comparatively, the precipitator is a more complicated piece of equipment.

4. Regulatory Agencies' Opinion

Based on conversations with Utah state agencies and Utah Power and Light, it appears that the State Regulatory Agencies are in favor of fabric filters.(13)

5. Base load Unit or Cycling Unit

The fabric filter is best applied to a base load unit. For a cycling unit, the fabric filter is not a good choice. The cycling unit usually goes through the acid dewpoint many times because of the variation of loads. This will damage filter bags and shorten bag life.

V. Conclusion and Recommendation

After dominating the electric utility industry as the particulate control for many years, the electrostatic precipitator has been giving ground to the fabric filter, especially in the western states. As discussed in the previous section, more and more western utilities have switched from electrostatic precipitators to fabric filters. For the generally conservative utility industry, this significant shift means that the performance of fabric filters are superior to the precipitators for future applications.

One major weakness of the fabric filter, as commonly recognized, is its lack of extensive experience on utility boilers. However, the existing fabric filters, which have accumulated installed capacity of more than 1,000 MW, have a very satisfactory operating record. As more and more fabric filters are put on-line, their performance has shown encouraging results.(14)(15) It appears that the fabric filter has already built its own case so that the lack of extensive utility experience should not be considered as an important factor anymore.

This report compares electrostatic precipitators and fabric filters covering such factors as coal properties, particulate collection efficiency, opacity, utilities' field experiences, costs, trend for future applications, and many others. The results shown are overwhelmingly in favor of fabric filters. Thus, this study concludes that the fabric filter is recommended for IPP as the particulate collection device.

VI TABLES

TABLE 1. INVESTMENT AND ANNUALIZED COSTS FOR FABRIC FILTERS AND ELECTROSTATIC PRECIPITATORS. (EPA ESTIMATES)

Fabric Filter

Boiler Size (MW)	Air-to-Cloth Ratio (acfm/ft^2)	Investment ($/kW)	Annualized Cost (mills/kWh)
200	2	69.47	2.30
500	2	58.45	1.96
1,000	2	53.56	1.81

Electrostatic Precipitator

Boiler Size (MW)	Specific Collection Area (acfm/ft^2)	Investment ($/kW)	Annualized Cost (mills/kWh)
100	400	76.06	3.59
500	400	52.53	2.46
1,000	400	50.15	2.34
100	550	90.67	4.29
500	550	68.45	3.21
1,000	550	65.13	3.04
100	650	98.22	4.65
500	650	80.71	3.77
1,000	650	73.37	3.43

TABLE 2 BUDGETARY COST DATA PROVIDED BY 10 EQUIPMENT VENDORS
(FOR ONE IPP BOILER UNLESS NOTED OTHERWISE)

Equipment supplier	Collector type	Cleaning Method*	SCA ($ft^2/10^3$ acfm)	A/C1 (ft/min)	Equipment cost 10^6 dollars	Total installed cost 10^6 Dollars	Total installed cost $/acfm
A	FF	RA	-	2.5/1	7.0	12.65	3.78
	cold ESP	-	686	-	14.0	23.0	6.87
B	FF	RA	-	2.0/1	7.45	-	-
	cold ESP	-	690	-	7.9	-	-
C	cold ESP	-	825	-	15.365	-	-
D	cold ESP	-	966	-	23.182	-	-
E	FF	RA	-	2.52/1	11.614	16.899	6.35
F	FF	RA	-	2.33/1	-	56.0 +	5.26
	cold ESP	-	595	-	-	54.9 +	5.08
G	cold ESP	-	595	-	10.962	-	-
H	FF	RA	-	2.04/1	10.2	18.435	6.93
	cold ESP	-	780	-	14.55	23.995	9.02
I	FF	P	-	5/1	12.8	-	-
J	cold ESP	-	560	-	60.0 +	76.0 +	7.14

*RA = reverse air
P = pulse
+Price given for all four boilers.

TABLE 3 ANNUALIZED COST ESTIMATE FOR AN ELECTROSTATIC PRECIPITATOR INSTALLED ON ONE IPP BOILER (GCA ESTIMATES)

Direct costs	
Direct (operating) labor	16,400
Supervision labor	3,416
Maintenance labor	41,000
Maintenance materials and replacement parts	51,660
Electricity	436,303
Waste disposal	1,135,525
TOTAL DIRECT COSTS	$1,684,304
Overhead	
Payroll	4,920
Plant	29,244
TOTAL OVERHEAD	$ 34,164
Capital Charges	
G & A, taxes and insurance	959,800
Capital recovery factor	2,178,746
Interest on working capital	27,370
TOTAL CAPITAL CHARGES	$3,165,916
TOTAL ANNUALIZED COST	$4,884,384
mills/kWh	1.05

TABLE 4 ANNUALIZED COST ESTIMATE FOR A FABRIC FILTER INSTALLED ON ONE IPP BOILER (GCA ERSTIMATES)

Direct costs	
Direct (operating) labor	30,748
Supervision labor	6,833
Maintenance labor	44,413
Maintenance materials and replacement parts	432,250
Electricity	535,948
Waste disposal	1,135,525
TOTAL DIRECT COSTS	$2,185,717
Overhead	
Payroll	9,224
Plant	133,703
TOTAL OVERHEAD	$ 142,927
Capital Charges	
G & A, taxes and insurance	737,400
Capital recovery factor	1,673,898
Interest on working capital	35,518
TOTAL CAPITAL CHARGES	$2,446,816
TOTAL ANNUALIZED COST	$4,775,460
mills/kWh	1.02

TABLE 5 RANGE OF COAL SAMPLE DATA
Intermountain Power Project

Coal Properties - Proximate Analysis, % Weight as Fired	
Total Moisture	4.5 - 11.0
Volatiles	36.14 - 42.34
Fixed Carbon	39.50 - 49.11
Ash	4.29 - 9.48
Ultimate Analysis, % Weight as Fired	
Carbon	62.35 - 75.42
Hydrogen	4.32 - 5.30
Oxygen	9.26 - 14.93
Nitrogen	1.02 - 1.46
Sulfur	0.44 - 0.78
Moisture	4.50 - 10.46
Ash	4.29 - 9.77
Chlorine	0.0 - 0.02
Ash Analysis, % Weight	
Fe_2O_3	3.53 - 10.75
CaO	4.82 - 20.65
MgO	0.96 - 4.68
K_2O	0.22 - 1.21
Na_2O	0.07 - 3.88
SO_3	3.38 - 14.63
P_2O_5	0.04 - 0.51
SiO_2	35.88 - 65.43
Al_2O_3	8.34 - 18.21
TiO_2	0.26 - 1.04
Fusion Temp. (Reducing) °F	
Initial Deformation	2085 - 2380
Softening (H=W)	2100 - 2410
Softening (H=1/2W)	2120 - 2475
Fluid	2135 - 2590
Fusion Temp. (Oxidizing) °F	
Initial Deformation	2130 - 2425
Softening (H=W)	2140 - 2435
Softening (H=1/2W)	2160 - 2445
Fluid	2170 - 2455

TABLE 6 SURVEY OF PRECIPITATOR PERFORMANCE ON U.S. WESTERN COALS

Utility (Station, Unit Number)	Capacity (MW)	Design Efficiency (%)	Test Efficiency (%)
Public Service Co. of Colorado			
Comanche No. 1	350	99.6	99.18
Comanche No. 2	350	99.6	99.18
Wisconsin Power & Light, Co.			
Columbia No. 1	520	99.5	91
Iowa Public Service, Co.			
George Neal No. 1	138	99.0	91
Commonwealth Edison			
Will County No. 3	299	98.5	99
Wauketan No. 7	360	99.1	98.7 - 99.7
Salt River Project			
Navajo No. 1	750	99.5	98.8 - 99.1
Navajo No. 2	750	99.5	98.8 - 99.1
Navajo No. 3	740	99.5	98.8 - 99.1
Public Service of New Mexico			
San Juan No. 1	330	99.5	99.8
San Juan No. 2	330	99.5	99.8
Iowa Power & Light, Co.			
Des Moines No. 10	71	99.3	99.3
Des Moines No. 11	116	99.3	99.5
Council Bluffs No. 1	47	99.3	98.0
Council Bluffs No. 2	90	99.3	98.3

TABLE 6 SURVEY OF PRECIPITATOR PERFORMANCE ON U.S. WESTERN COALS (Cont'd)

Utility (Station, Unit Number)	Capacity (MW)	Design Efficiency (%)	Test Efficiency (%)
Colorado - Ute. Elec., Inc.			
Hayden No. 1	200	99.6	99.19
Hayden No. 2	250	99.6	97 or 98
San Antonio Public Service Board			
J. I. Deely No. 3	430	99.4	86 - 91
J. I. Deely No. 4	430	99.4	86 - 91
Omaha Public Power Dist.			
Wright No. 8	90	99.3	99
Nebraska Public Power Dist.			
Sheldon No. 1	105	97.9	97.2 - 97.6
Sheldon No. 2	120	97.9	97.2 - 97.6
Colorado Spring Department of Public Utilities			
Martin Drake No. 7	137	99.35	99.2
Arizona Public Service			
Four Corners No. 4	750	97	92 - 94
Four Corners No. 5	750	97	92 - 94
Southern California Edison			
Mohave No. 1	790	97.9	97 - 98.6
Mohave No. 2	790	97.9	97 - 98.6

TABLE 7 SUGGESTED COLLECTING EFFICIENCIES OF FABRIC FILTER AND ELECTROSTATIC PRECIPITATOR BASED ON PARTICLE SIZE DISTRIBUTION

Particle Size	Fabric Filter Efficiency (%)	Electrostatic Precipitator Efficiency (%)
0.3	99.8	95.19
0.5	99.8	95.1
1.0	99.8	96.32
2	99.8	99.26
3	99.8	99.37
5	99.8	99.59
7	99.8	99.79
10	99.8	99.93

TABLE 8 FUTURE INSTALLATION OF FABRIC FILTERS IN THE WESTERN UNITED STATES

Utility (Units)	Size (MW)	Manufacturer	On-Line Date
Arizona Public Service			
Four Corners No. 4	750	Buell	1981
Four Corners No. 5	750	Buell	1981
Basin Electric Power Corporation			
Antelope Valley No. 1	440	Western Precipitation	1982
Antelope Valley No. 2	440	" "	1983
City of Colorado Springs			
Nixon No. 1	200	Western Precipitation	1980
Colorado-Ute Elec. Assoc.			
*Craig No. 3	400		
Houston Power and Light			
Parish No. 8	550	Research Cottrell	1983
Nebraska Public Power Dist.			
*Gentleman No. 3	650		
Nevada Power Co.			
Reid Gardner No. 4	250	Carborundum	1983
Otter Tail Power Co.			
Coyote No. 1	440	Western Precipitation	1981
Public Service of Colorado			
Cherokee No. 2	100	Buell	1980
Cherokee No. 3	150	Buell	1980
*Southeast No. 1	500		
*Southeast No. 2	500		

TABLE 8 FUTURE INSTALLATION OF FABRIC FILTERS IN THE WESTERN UNITED STATES (Cont'd)

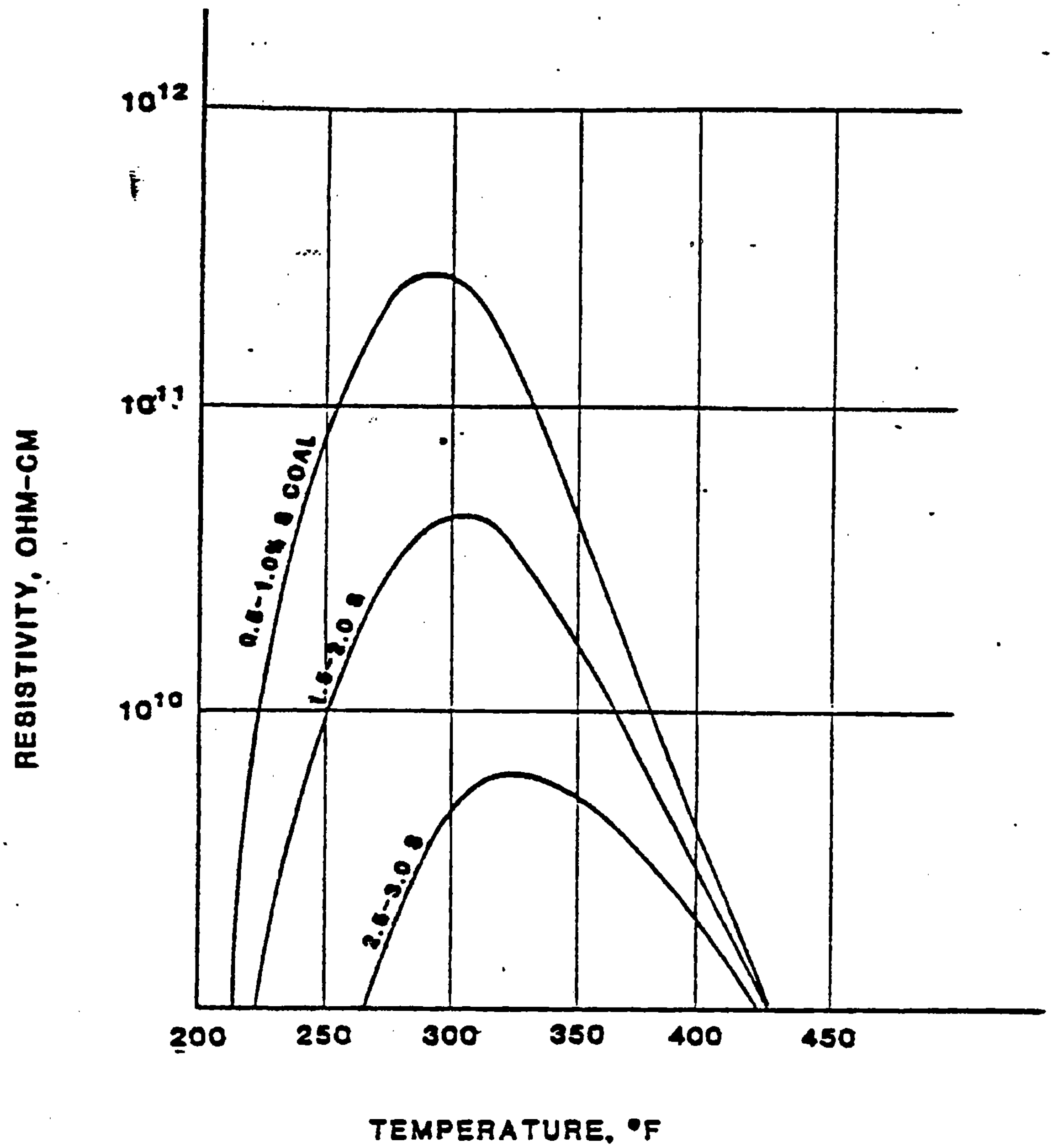
Utility (Units)	Size (MW)	Manufacturer	On-Line Date
Salt River Project			
*Coronado No. 3	350		
Sierra Pacific Power			
North Valmy No. 1	250	Carborundum	1980
*North Valmy No. 2	250		
Southwestern Public Service			
Tolk No. 1	550	Industrial Clean Air	1982
Tolk No. 2	550	" " "	1984
Tucson Electric Power			
Springville No. 1	350	Western Precipitation	1985
Springville No. 2	350	Western Precipitation	1986
Utah Power and Light			
Hunter No. 3	440	Carborundum	1983
Hunter No. 4	440	"	1985

*No contract awarded yet but leaning toward fabric filter

TABLE 9 FUTURE INSTALLATION OF ELECTROSTATIC PRECIPITATORS IN THE WESTERN UNITED STATES

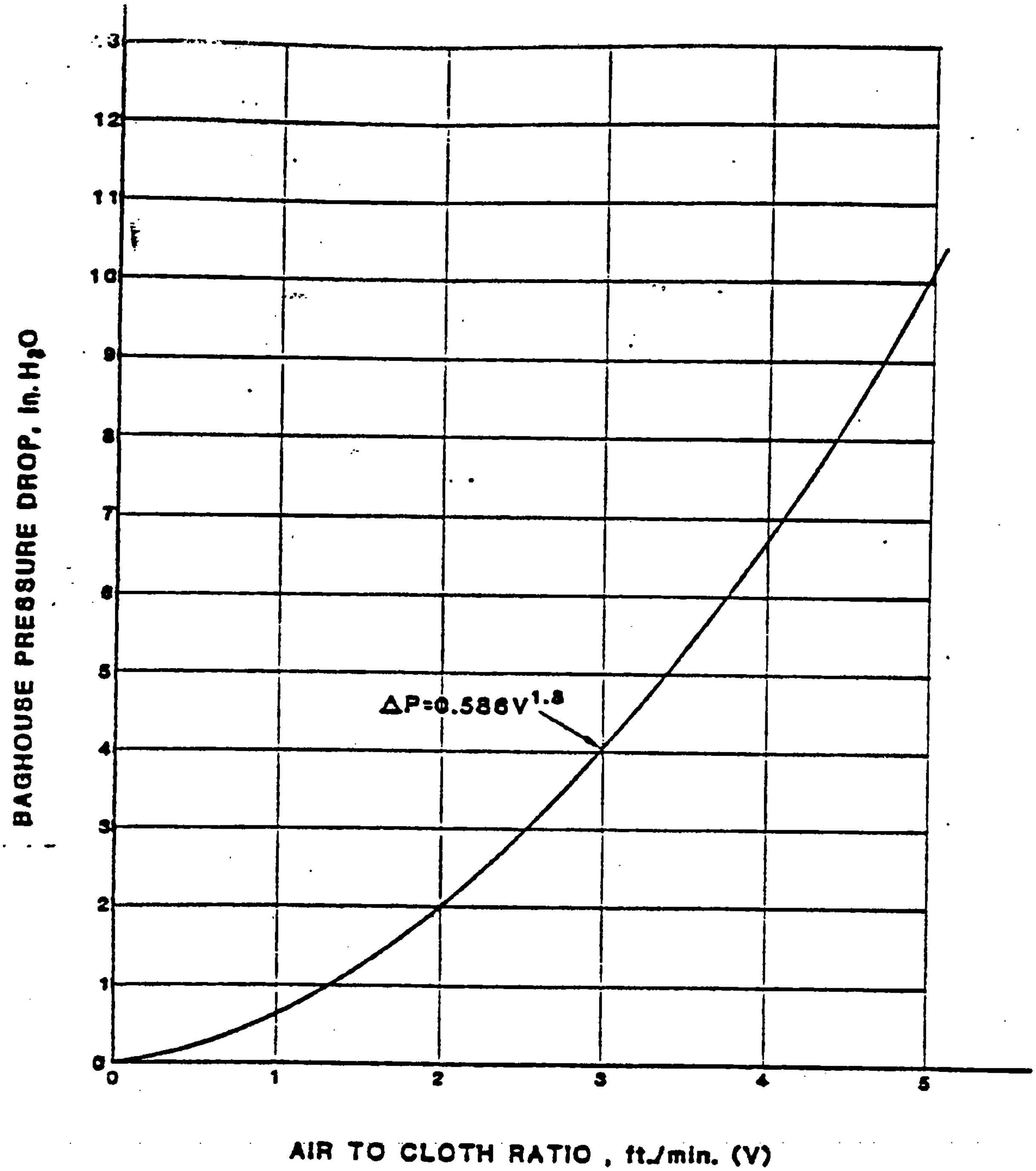
Utility (Units)	Size (MW)	Manufacturer	On-Line Date
Arizona Public Service			
Cholla No. 4	350	Universal Oil Prod.	1981
Colorado-Ute. Elec. Assoc.			
Craig No. 1	410	NA	1981
Houston Lighting and Power			
Parish No. 7	550	Western Precipitation	1980
Nebraska Public Power Dist.			
Gentleman No. 2	680	Environmental Elements	1981
Salt River Project			
Coronado No. 2	350	Western Precipitation	1980
Southwestern Elec. Power			
Welsh No. 2	550	Research Cottrell	1980
Texas Power and Light			
Sandow No. 4	550	C-E Walther	1980
Utah Power and Light			
Hunter No. 2	400	Buell	1980

VII FIGURES



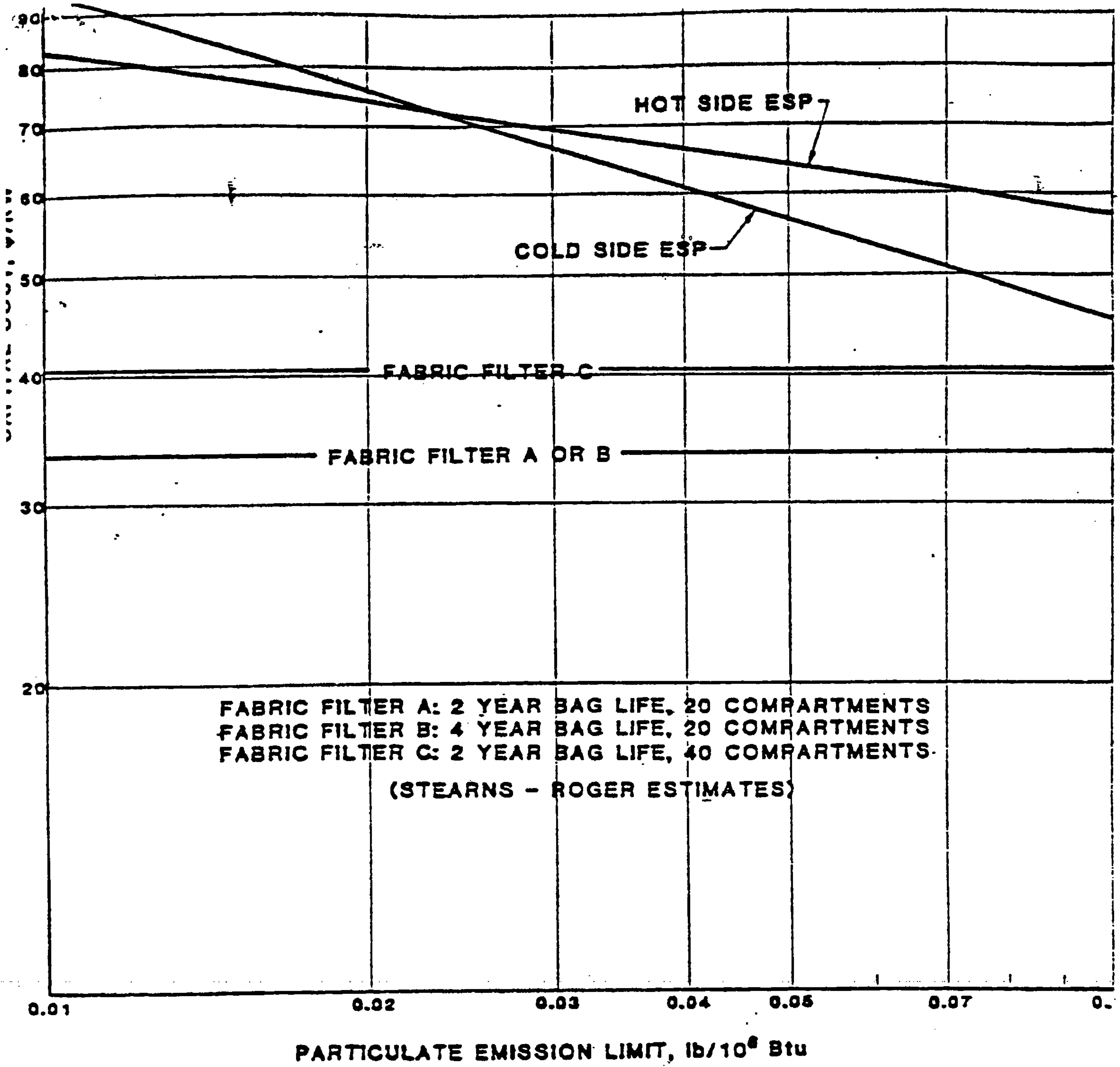
RESISTIVITY, TEMPERATURE, FUEL SULFUR RELATIONSHIPS

FIGURE 1



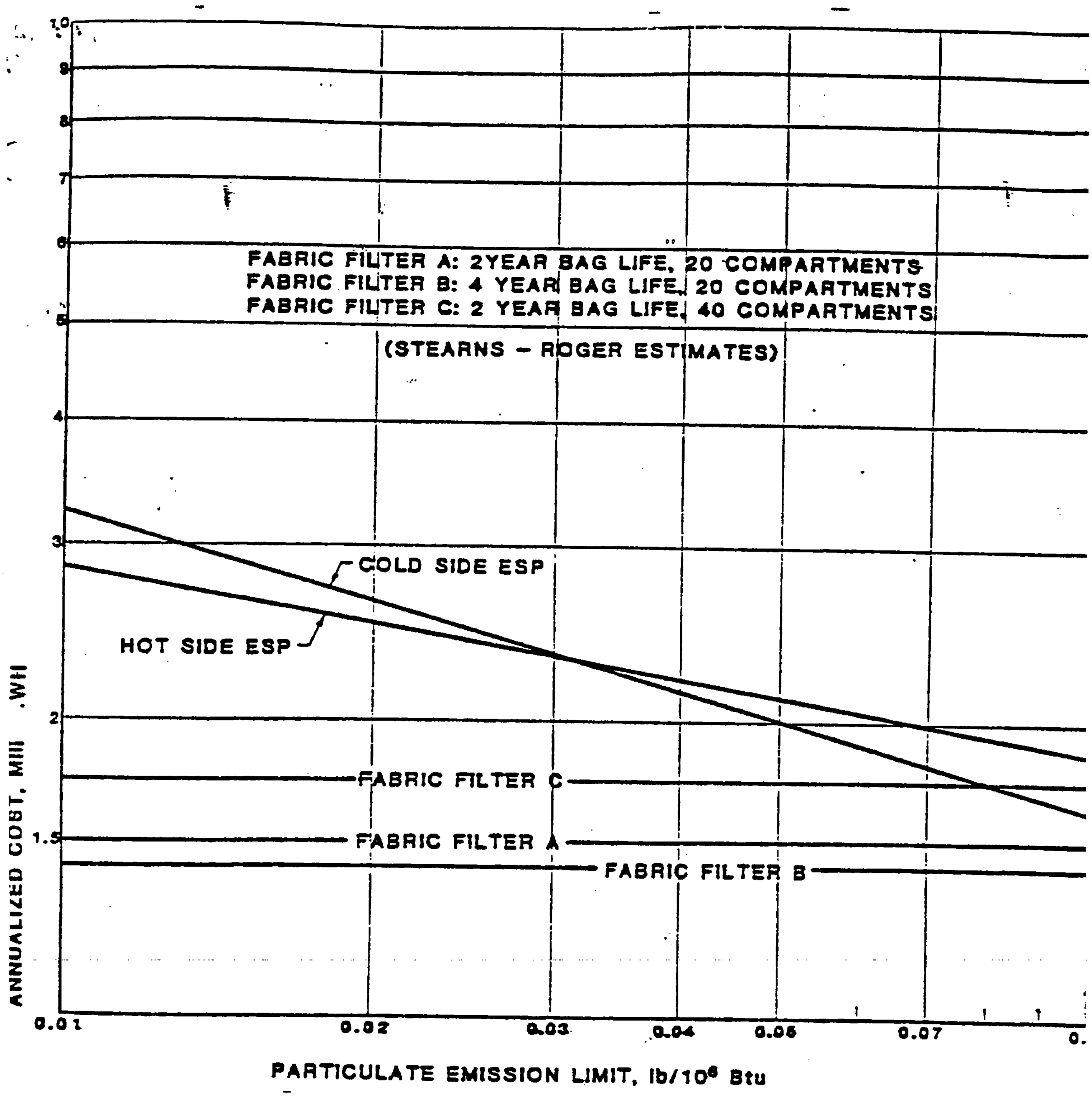
BAGHOUSE PRESSURE DROP VERSUS
AIR TO CLOTH RATIO

FIGURE 2



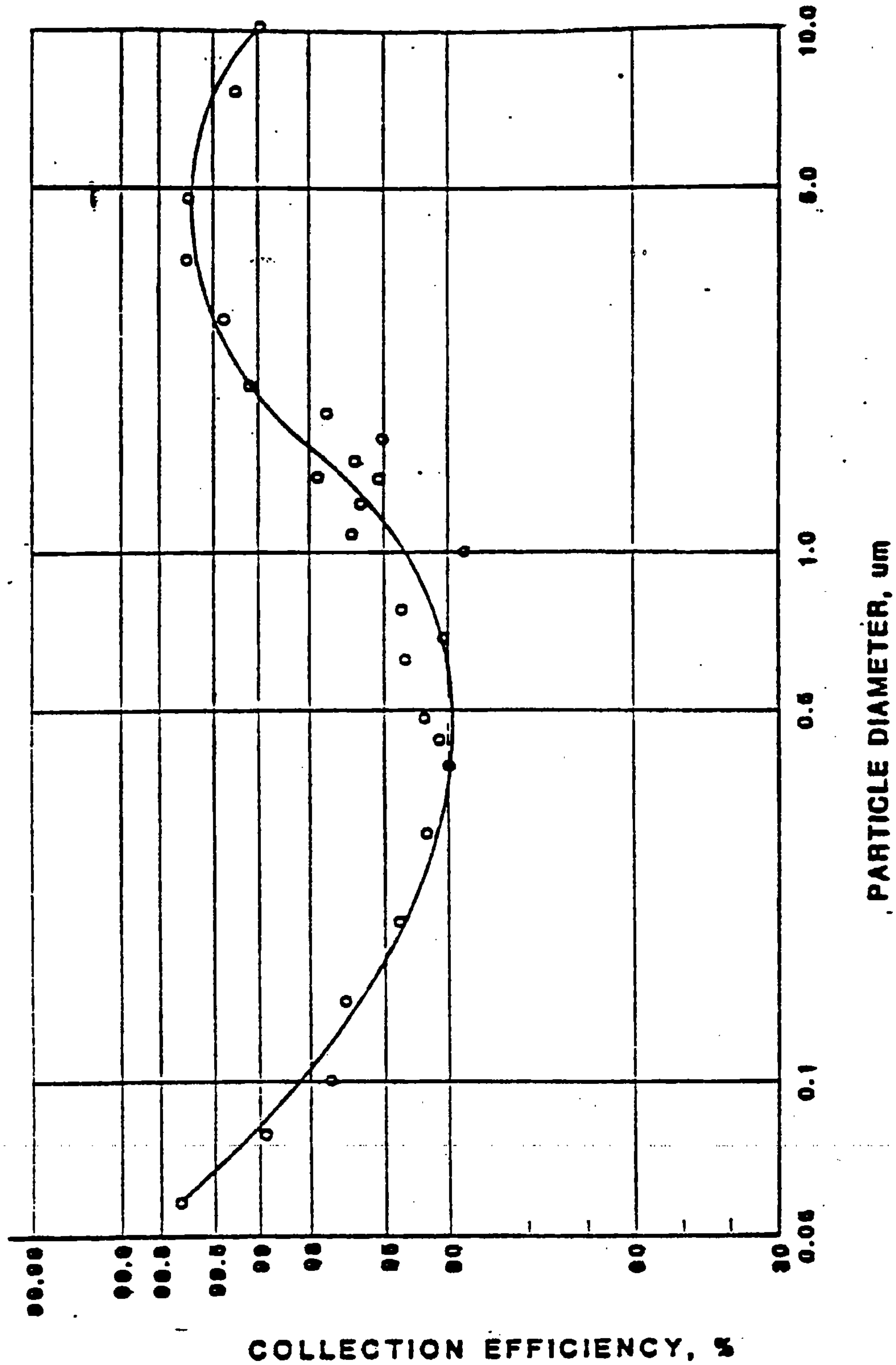
CAPITAL COSTS FOR 500 MW PARTICULATES COLLECTORS
IN 1980 DOLLARS

FIGURE 3



ANNUALIZED COSTS FOR 500 MW PARTICULATES COLLECTORS IN 1980 DOLLARS

FIGURE 4



MEASURED FRACTIONAL EFFICIENCIES FOR A COLD-SIDE PRECIPITATOR WITH A BOILER BURNING LOW SULFUR COAL

FIGURE 5

VIII REFERENCES

REFERENCES

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